A randomized, placebo-controlled crossover trial of a decaffeinated energy drink shows no significant acute effect on mental energy

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ABSTRACT

Background: "Energy drinks" are heavily marketed to the general public, across the age spectrum. The efficacy of decaffeinated energy drinks in enhancing subjective feelings of energy (s-energy) is controversial.

Objective: The authors sought to test the efficacy of the caffeine-free version of a popular energy drink compared with a placebo drink.

Methods: This study was a randomized, double-blind, placebo-controlled, crossover trial in 223 healthy men and women aged 18–70 y with intention-to-treat and completers analysis. Participants were randomly assigned to consumption of either the decaffeinated energy drink or a placebo drink on testing day 1, and the other drink a week later. A battery of computer-based mood and cognitive tests to assess s-energy was conducted at baseline and at 0.5, 2.5, and 5 h post-ingestion. The main outcome measures were *1*) mood, which was assessed by using a General Status Check Scale and the Profile of Mood States 2nd edition brief form, and *2*) cognitive measures, including the N-back task (reaction time and accuracy), Reaction Time test, Flanker task (distraction avoidance), and Rapid Visual Information Processing test.

Results: No statistically significant or meaningful benefits were observed for any outcome measure, including mood and cognitive measures. Analyses of mean differences, slopes, and median differences were consistent.

Conclusions: No differences were detected across a range of mood/cognitive/behavioral/s-energy–level tests after consumption of the energy drink compared with a placebo drink in this diverse sample of adults. Thus, we found strong evidence that the energy drink is not efficacious in enhancing s-energy levels, nor any related cognitive or behavioral variables measured. In light of federal regulations, these findings suggest that labeling and marketing of some products which claim to provide these benefits may be unsubstantiated. This trial was registered at www.clinicaltrials.gov as NCT02727920. *Am J Clin Nutr* 2020;111:719–727.

Keywords: dietary supplements, intervention, adults, volunteers, Baltimore, United States

Introduction

Energy drinks and shots are commonly available, and consumption in the United States has been growing since their introduction in 1997 (1). Manufacturers claim that the products provide a broad range of benefits, including increased alertness,

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Data sharing: Information about the study, including the protocol, and the de-identified study data will be deposited with the digital repository of the Inter-University Consortium for Political and Social Research (ICPSR) by December 2020 (within 18 months of the date the data system closed to further data entry). Data described in the manuscript, code book, and analytic code will be made publicly and freely available without restriction at the ICPSR Website https://www.icpsr.umich.edu/.

Supplemental Tables 1 and 2 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/ajcn/.

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Abbreviations used: BF, Bayes factor; ITT, intention to treat; POMS-2, Profile of Mood States 2nd edition brief form; RVIP, Rapid Visual Information Processing; s-energy, subjective feelings of energy.

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improved cognitive performance, and sustained "energy" (2). The drinks are promoted as an aid for active/busy people who need "that extra boost," or wish to "leave grogginess behind." The efficacy in terms of producing subjective feelings of energy (s-energy) enhancement associated with decaffeinated energy drinks is controversial; it is not clear that ingredients other than caffeine would increase s-energy.

Adverse cardiovascular events (3–7) and adverse neurological effects (5) have been reported with consuming caffeine-containing energy drinks; 2 recent studies found that athletes who consumed them were more likely to experience nervousness, anxiety, and trouble sleeping hours after competing (8, 9). This is a concern, especially among adolescents, who may consume energy drinks in excess or with alcoholic beverages (5). The adolescent market accounts for nearly $2.3 billion of US energy-drink sales (10), and >50% of college students report consuming them at least monthly (11). Moreover, while causality has not been proven, energy drink consumption is associated with substance abuse and risk-taking behaviors (5, 12). Independent of any harm, use of these products is predicated on the supposition that they effectively provide the benefits claimed.

Regarding efficacy, energy drinks commonly contain caffeine, B-vitamins, taurine, sugars, and other ingredients, depending upon the brand (13). Most contain caffeine (14), but it remains unclear whether energy drinks increase s-energy due to caffeine, other nonherbal (vitamins, minerals, and amino acids) and herbal ingredients, or a combination of ingredients (5). Even plain water can have "energy increasing" effects on s-energy when touted as having them (15).

When comparing caffeinated with decaffeinated versions of the same energy drink, recent studies found that the caffeinated version increased blood pressure compared with the decaffeinated version (16), making the latter potentially more attractive from a safety perspective. To our knowledge, however, the relative efficacies for s-energy enhancement of caffeinated compared with decaffeinated versions of the same energy drink have not been evaluated in a controlled fashion. A recent study reported that, for a particular energy drink, both caffeinated and decaffeinated versions were associated with significantly increased s-energy 1 h after consumption, but the caffeinated drink showed a greater boost, sustained for at least 3 h (17). No placebo control was used, so it cannot be concluded whether the decaffeinated drink had any effect at all. However, a very recent randomized, double-masked, placebo-controlled, crossover study in young healthy volunteers (7) found an association between consuming energy drinks and changes in QT intervals and blood pressure that could not be attributed to caffeine. The authors concluded that further investigation of the particular ingredient or combination of ingredients in different types of energy drinks that might explain their findings is urgently needed.

Previous studies of the efficacy of energy drinks lacked sufficient power and were generally not placebo controlled. It is unclear whether ingredients other than caffeine, which has well-documented effects, increase s-energy.

The aim of this study, designed by the authors under contract with the State of Oregon Department of Justice, was to compare the efficacy of a caffeine-free energy drink with claimed s-energy effects with that of a placebo drink. Primary outcomes were mood and cognitive measures.

TABLE 1 Composition of the study drinks

Drink ingredients	Amount per serving[1]
Energy drink	
Vitamin B6 (pyridoxine hydrochloride)	40 mg
Folic acid	400 μg
Vitamin B12 (cyanocobalamin)	500 μg
Sodium	18 mg
Energy blend	
Taurine, choline, glucuronic acid (as or from glucuronolactone), *N*-acetyl L-tyrosine, L-phenylalanine, and malic acid	2009 mg
Caffeine	6 mg
Other ingredients	
Purified water, natural and artificial flavors, sucralose, potassium sorbate, sodium benzoate, and EDTA (to protect freshness)	—
Placebo	
Water, sucralose, citric acid, orange extract, lemon juice, sodium benzoate (preservative), potassium sorbate, and red beet (for color)	—

[1] Serving size 1.93 fluid oz (57.08 mL).

Methods

Study design and participants

This was a randomized, double-blind, placebo-controlled, crossover study. The protocol was approved by the institutional review board of the Johns Hopkins Bloomberg School of Public Health, with written informed consent obtained from all study participants.

Participants were men and women recruited locally from the general public and college-aged students who met the following screening inclusion criteria by self-report: 18–70 y old; nonsmoker; no diagnosed or treated cognitive or psychiatric conditions; no diagnosed or treated diabetes, hypoglycemia, or thyroid conditions; no current use of prescription stimulants; no allergies or sensitivities to ingredients (including caffeine) in the test drinks; no diagnosed phenylketonuria; fluent in reading English; high school graduate as lowest educational level; computer literate; and able to fast for 7 h.

Study drinks

Ingredients of the decaffeinated energy drink (5-hour Energy Decaf, Living Essentials, LLC), serving size 1.93 fluid ounces (57.08 mL) are presented in **Table 1**.

The placebo was designed to be similar in taste and color to the energy drink and was confirmed by independent laboratory testing to contain no measurable caffeine. Its ingredients are also listed in Table 1.

All samples of the energy drink were obtained through Amazon.com, and the placebo was manufactured by a food chemist who prepared (in a certified laboratory at Medifast Inc.) dark-colored containers of both the placebo and the energy drink, labeling them with the participant's study ID, date of planned administration, and testing day number (1 or 2). The placebo trial procedure was documented in writing, including what was prepared and a study product accountability record for each dispensing of the active and placebo drinks. Administration of

study drinks was double-blinded: only the food chemist was aware of which designation applied to the test and which applied to the placebo drink until the study and statistical analyses were completed. The quality of blinding was tested on staff and investigators, who reported no differences between the unlabeled drinks in color or taste.

Randomization and masking

The 2 treatments were coded as A or B, and a randomization schedule was generated to assign treatment order randomly. A list of 300 treatment order combinations was created to indicate in what sequence a participant would receive his or her treatment (A then B, or B then A). The list contained 150 AB and 150 BA combinations, which were then sorted into a random order to obtain equal numbers of order types randomly distributed. Participants were assigned the order types based on their participant number, which was assigned upon arrival on their first testing day.

Study procedures

Individuals were recruited using posters displayed around the university campuses, flyers, and announcements on radio stations, the Internet, www.clinicaltrials.gov (registration number NCT02727920), and word of mouth. During screening, participants were asked to choose 2 consecutive weekends in March, April, or May for their testing days. Thus, a washout period of at least 6 days followed the first assessment day. During the washout period, participants could engage in their normal daily activities. Standardized instructions were given regarding avoiding alcohol and tobacco and any food or drinks for 12 h prior to the study to account for any caffeine use the day prior. The same procedures followed on the first testing day were applied at approximately the same time on the second testing day, with participants receiving the other test drink.

The pulse rate of study participants was measured using a pulse oximeter (CMS 500DL Fingertip Pulse Oximeter, Amazon.com) ~1 h after consumption of the test drink on each of the 2 test days. Body weight was measured on testing day 1 in all participants, without coats or shoes, using a digital scale (model UM029, Tanita Corporation). A light, standardized lunch and water beverage were provided after informed consent was obtained.

Participants were first asked to complete a baseline questionnaire; then a baseline battery of computer-based tests specifically tailored to assess s-energy was conducted (described in detail in Study measures). These baseline measures took approximately 40 min to complete. Participants were then administered the energy drink or placebo to consume over a 2-min period while being observed to ensure consumption. The battery of computer-based tests to assess s-energy was readministered 30 min, 2.5 h, and 5 h after consumption of the test drink on each testing day.

Study measures

Low s-energy and fatigue can be related to long work hours, inadequate sleep, or stress in coping with the demands of daily life (14). Although energy level is often difficult to define, it has been described as "the mental will to engage in an activity" (18). A 2004 workshop proposed a model of mental energy comprising 3 primary dimensions: cognition, mood, and motivation, defined as "the ability to perform mental tasks, the intensity of feelings of energy/fatigue, and the motivation to accomplish mental and physical tasks" (19). Lieberman (14) proposed standardized methods for assessing mental energy and concluded the following: "cognitive tests that assess vigilance, ability to sustain attention, and choice reaction time are optimal for assessment of mental energy", whereas for self-ratings, "particular moods, such as vigor and fatigue, are closely identified with mental energy, as measured by the POMS-2 and other questionnaires". **Table 2** includes the self-rating and cognitive measures that were administered to assess these variables.

The entire intervention was sequenced and timed as follows: *1*) At 12:00 on testing days 1 and 2, participants signed in, completed consent forms, and consumed a standardized lunch. Participants were in a free-living state prior to the 12:00 appointments. *2*) Baseline tests (duration ~70 min) were completed on testing day 1 only; participants completed the baseline survey (duration ~30 min) and the baseline computer-based attention tests (duration ~40 min). On testing day 2, participants completed only the baseline computer-based tests (duration ~40 min). They were then asked to engage in activities (e.g., reading or watching movies) for the same amount of total time as on testing day 1.

After the baseline testing period on both testing days 1 and 2, the participants drank a beverage (the caffeine-free energy drink or the placebo) and completed the following computer-based tests at 3 timepoints: At timepoint 1 (30 min after consuming the drink), participants completed the POMS-2, N-back task, Reaction Time test, Flanker task, and RVIP test. At timepoints 2 and 3 (2.5 and 5 h postdrink, respectively), participants completed the N-back task, Reaction Time test, Flanker task, and RVIP test. At timepoint 3 (5 h postdrink), participants completed the N-back task, Reaction Time test, Flanker task, and RVIP test. On testing day 1, weight was measured after timepoint 1; on days 1 and 2, pulse was measured right after the completion of tests.

Design and variables

A battery of tests of energy levels was conducted at baseline and at 0.5, 2.5, and 5 h following crossover–randomly assigned administration of the energy drink and placebo during 2 consecutive weekends. Differences between experimental conditions were evaluated for each of the following tests: the POMS-2, N-back task, Reaction Time test, Flanker task, and RVIP. The data that were analyzed for these tests included accuracy, error assessment, and reaction-time performance.

Statistical power

Sample size was calculated for a 2-period crossover design assuming 80% power and a 2-sided test with a significance

TABLE 2 Description of the self-rating and cognitive measures used to assess the variables of the trial[1]

Measures	Description
Self-rating measures	
General Status Check	Ad hoc subjective scale validated by content validity comprising 2 questions about current self-perceived energy and alertness asked 30 min after consumption of each drink. Question 1: "How energetic are you feeling right now?"; question 2: "How alert are you feeling right now?" Rated on a 5-point scale from 0, "not at all" energetic/alert, to 4, "very" energetic/alert.
POMS-2	Assessment of current mood (20) consisting of 35 adjectives, each rated on a 5-point scale ranging from 0, "not at all," to 4 "extremely." Six mood scales (ranging from 0–100) summed separately: anger-hostility, confusion-bewilderment, depression-dejection, fatigue-inertia, tension-anxiety, and vigor-activity. Total task duration 5–10 min.
Cognitive measures	
N-back task	Measure of sustained, selective attention (working memory performance) and impulsivity (21). Images of objects (e.g., basketball, bike) are presented via computer screen. Participants press "YES" or "NO" to indicate whether the object is the same as the *n* previously (e.g., 1 back is the previous object, 2 back is the second previously shown object. The 2-back task was used in the present study and was scored for speed (reaction time) and accuracy. Task time 10 min. For performance assessment, we created a combined score of reaction time (speed in milliseconds) × (100/accuracy). Reported interactions between caffeine (and other energy substances) and N-back task performance: people get better at the task after consuming caffeine (22, 23).
Reaction Time test	1–2-min-task tests high-level distraction (emotion), physical distraction, attention, and interference. Includes 4 conditions: baseline (no distraction), sensory distraction (distractors are basic shapes), emotional distraction (included emotional images like war, car crashes, etc.), and cognitive distraction (distractors involved math problems). Participant is confronted with a variety of speed–response tasks, e.g., the person presses the spacebar as soon as a red square appears on the screen. The test provides a value in milliseconds for the average of 5 tries to respond to the red square. A variety of images were included to try to distract the person during their response. (https://www.learner.org/courses/neuroscience/interactives/interactive1.html)
Flanker task	5-min computer-based arrow task to examine attentional filtering mechanisms related to distractor interference, i.e., if there are different processes depending on different stimuli; we used an adapted version (24). Stimuli are up- or down-pointing arrows. In distracter-absent trials a single target arrow is displayed in the center of the screen; in distracter-present trial the target arrow is flanked by 4 distracting arrows (2 on the left and 2 on the right). Orientation of flankers could be either congruent or incongruent with respect to the direction of the central target arrow. Examines attentional filtering mechanisms related to distractor interference; i.e., do participants avoid distraction better after energy drink than placebo consumption? Caffeine enhances this task (22). Task has been used to assess the effects of caffeine on reaction time (22). (https://www.learner.org/courses/neuroscience/interactives/interactive1.html)
RVIP test	4-min task tests sustained attention, which relies heavily on working memory (25, 26). We used an adapted task (26); single digits are presented for 600 ms continuously in semirandom order, 100 digits/min. Participants press the response button as soon as they detect 3 consecutive odd or even digits in ascending order (e.g., 2,4,6; 5,7,9). Potential correct hits are presented 8/min (32 targets in total). The total number of correct hits (accuracy), reaction time for correct hits, and false alarm rate are scored. Assesses the caffeine effect on mood, memory, and information processing (27).

[1]POMS-2, Profile of Mood States 2nd edition brief form; RVIP, Rapid Visual Information Processing.

level of 5%. Standard formula (28) calculations revealed that a sample size of 208 participants (completers) provides 82% power to detect a standardized effect size of $d = 0.2$ for a paired *t*-test, when the correlation between the measurements is 0.50. Power increases as additional data are included for participants with partial data in the ITT analysis. A total sample size of $n = 223$ would have 80% power to detect an effect size as small as $d = 0.18$ if data were complete. A standardized effect size of $d = 0.20$ is considered a small effect, and effect sizes of this size or larger are generally considered meaningful in cognitive psychology (29). The sample size is, therefore, sufficient to allow us to detect quite small effects. In addition to sample size measures typical of neuroscience work, our sample size estimate also considered measures typical of clinical/public health research. Therefore, the current study has sufficient power to detect small and meaningful differences between drinks.

Statistical analyses

Hypotheses were evaluated under intention to treat (ITT) using 2 methods. The primary analyses are linear mixed-effect models for 223 participants who were randomized and had outcome data from ≥1 visit. Multiple imputation was performed under the missing-at-random assumption to impute missing data on each measure, including missing participant data for day 2 (30–32). Imputation was performed using Monte Carlo Markov chains with multiple chains, conditioning on observed demographics and available outcome measures, making no assumption about the joint distribution of these measures. Twenty imputed datasets were generated for 223 participants. Linear mixed models were fitted separately in each dataset, and results from these models were combined, accounting for the within- and between-imputation variances. These analyses were performed using the

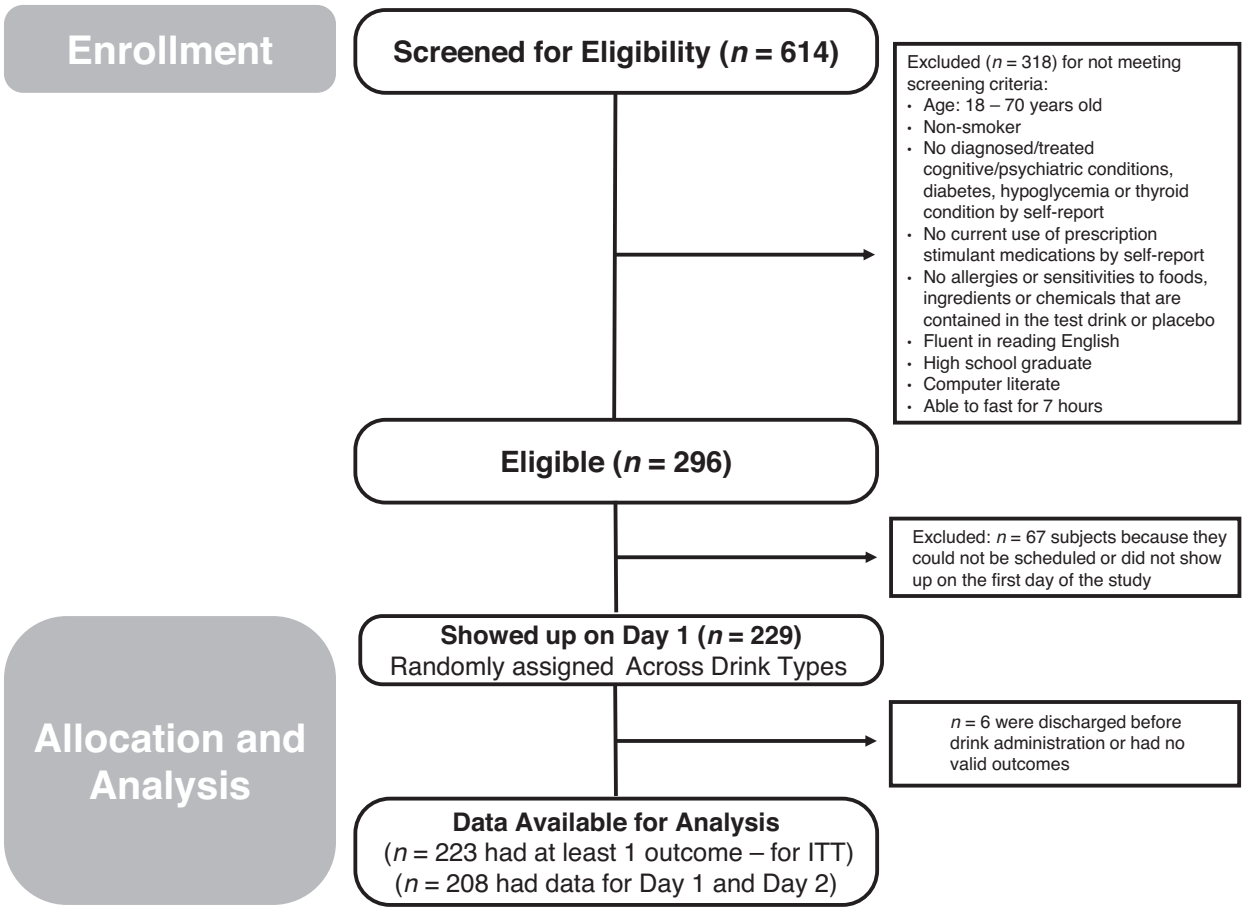

FIGURE 1 Trial design and sampling flow chart. The flow chart shows the stages of the sampling process, the number of excluded individuals, and the reasons for exclusion. ITT, intention to treat.

MI and MIANALYZE procedures in SAS. Analyses of the cognitive tasks included effects for group, time (baseline and 0.5, 2.5, and 5 h after drink consumption), and group by time interaction. Contrasts were performed to test the treatment effect as the difference between groups in their respective differences from baseline (0.5 h − baseline, 2.5 h − baseline, and 5 h − baseline). Paired *t*-tests were performed as secondary analyses on the 208 participants whose data included completion of both drinks.

To enhance robustness, log transformations were applied to reaction time measures with skewed distributions, and analyses were performed on both the untransformed and log-transformed data. Three outliers were removed that were >3 SDs away from the means after skewed data were normalized. Sensitivity analyses with the outliers included showed no substantive differences in results. Bayes factors (BF) were also computed to evaluate the evidence provided by the data for the null hypothesis of no effect, relative to the alternative (33). These factors were computed with the complete data, which were analyzed as observed, and with missing data imputations under the ITT protocol (34). The BF analyses were implemented in the R BF and MICE packages (35, 36). All analyses were conducted and verified by 2 statisticians. Results were consistent between analysts, i.e., nonsignificant for both, and robust to transformations and various outlier specifications. Statistical significance was set during the design phase at $P < 0.05$ (2-tailed).

Results

As presented in **Figure 1**, a total of 614 individuals were screened via phone or email, and 296 met all inclusion criteria; 67 of these were excluded because they could not be scheduled or did not appear on testing day 1. The remaining 229 participants were randomly assigned to the order in which they would receive the 2 tested drink types (A then B or B then A). The 223 participants who completed ≥1 outcome measure were included in a modified ITT analysis with multiple imputation, and the 208 who completed both timepoints were analyzed separately. Demographic characteristics of the analyzed sample are shown in **Table 3**.

Self-rating measures

Table 4 presents results from ITT analysis for pulse, general status check, and POMS-2 measures. Descriptive statistics are presented for the observed data, and treatment effects and *P* values calculated from linear mixed models on data from

TABLE 3 Characteristics of the analyzed study participants[1]

Characteristic	Value
Age, y (n = 223)	38.45 ± 13.31
18 to <30	34.98%
30 to <50	38.12%
50 to <70	26.91%
Sex (n = 223)	
Female	43.05%
Caffeine sensitivity (*n* = 218)	
Yes	16.06%
BMI, kg/m^2 (*n* = 220)	
Overall	28.36 ± 7.60
Category	
15 to <18 .5	2.73%
18.5 to <25	36.36%
25 to <30	26.36%
30 to <35	19.09%
35 to <55	15.45%
Race/ethnicity (*n* = 218)	
African American	55.50%
White	24.77%
Asian	11.47%
Hispanic	5.05%
Other	3.21%

[1]Values are mean ± SD or percentage.

multiple imputation. Bayes factors (BFs) are reported, which indicate the strength of evidence for the null hypothesis of no difference between groups. None of the variables showed significant differences between conditions at $P < 0.05$. BFs were smallest (closer to 1) for General Status Check items indicating the least evidence for the null hypothesis (i.e., some evidence for difference between groups), for the placebo group fared better than the energy drink group. The BFs are large for POMS-2 measures, indicating strong evidence that the effects of the 2 drinks are similar.

Supplemental Table 1 displays results of paired *t*-tests of the participants who completed outcome measures for both drinks, which showed a significant effect for Question 2: "How alert are you feeling right now?" ($P = 0.039$) but a nonsignificant effect at the 0.05 level for Question 1: "How energetic are you feeling right now?" ($P = 0.060$). In both cases the numerical differences between the energy drink and the placebo drink were higher for the placebo condition; specifically, participants reported more "energy" and higher "alertness" after placebo.

Cognitive measures

Table 5 displays results from ITT analyses with multiple imputation for all cognitive outcome measures by treatment group. Descriptive statistics are presented for the raw data, and estimated treatment effects, SEs, and *P* values calculated from linear mixed models, as well as BFs, are presented for imputed data. Only 1 result was significant, which was for the log-transformed version of time on the N-back task after 5 h, for which the participants improved more in the placebo drink condition than the energy drink condition ($P = 0.043$). None of the other measures (i.e., Reaction Time task, Flanker task, and RVIP test) showed any meaningful or statistically-significant differences in performance between the 2 drink types across all timepoints. Analyses of the 208 completers in **Supplemental Table 2** showed no significant differences between conditions from paired *t*-tests on changes from baseline.

Discussion

This experimental study with a crossover design revealed no statistically significant or substantively appreciable improvements in cognitive, behavioral, or s-energy performance after consumption of the caffeine-free energy drink compared with the placebo drink. Two outcome measures even showed improved results for the placebo condition (i.e., the log-transformed version

TABLE 4 Treatment effect on pulse, general status check, and the POMS-2 measures, with multiple imputation[1]

	Treatment						
	Energy drink		Placebo		Treatment effect[2]		
Outcome	*n*	Mean ± SD	*n*	Mean ± SD	Estimate ± SE	*P* value	BF
Pulse, beats/min	215	79.2 ± 14.7	215	81.2 ± 15.5	−1.9 ± 1.3	0.149	2.93
General Status Check[3]							
Question 1: Energetic	215	1.9 ± 0.9	216	2. ± 1.0	−0.2 ± 0.1	0.097	1.80
Question 2: Alert	215	2.1 ± 0.8	216	2.2 ± 01.0	−0.2 ± 0.1	0.060	0.92
POMS-2							
Anger-hostility	204	43.2 ± 6.5	201	43.0 ± 7.6	−0.4 ± 0.9	0.650	11.64
Tension-anxiety	204	41.9 ± 7.8	201	41.2 ± 7.0	0.8 ± 0.9	0.350	6.83
Confusion-bewilderment	204	42.3 ± 7.0	201	42.2 ± 7.0	−0.0 ± 0.7	0.979	12.56
Depression-dejection	204	45.2 ± 6.5	201	44.7 ± 5.9	0.7 ± 0.6	0.245	6.71
Fatigue-inertia	204	41.0 ± 8.1	201	41.2 ± 8.7	−0.3 ± 1.0	0.769	11.72
Total mood disturbance	203	45.8 ± 8.7	201	45.5 ± 8.0	0.1 ± 0.9	0.925	11.27
Vigor-activity	203	43.5 ± 10.2	202	42.8 ± 10.4	0.7 ± 1.0	0.470	8.93

[1]BF, Bayes factor; POMS-2, Profile of Mood States 2nd edition brief form.

[2]Treatment effect from linear mixed models, accounting for the correlation between visits, with pooled results after multiple imputation with 20 imputed datasets (*n* = 223).

[3]General Status Check: question 1 "How energetic are you feeling right now?" Question 2 "How alert are you feeling right now?" Answers rated on a 5-point scale from 0, "not at all" energetic/alert, to 4, "very" energetic/alert.

TABLE 5 Treatment effect on reaction times for cognitive tasks, with multiple imputation[1]

	Treatment									
	Energy drink		Placebo		Treatment effect				Log transformed[2]	
Cognitive task timepoint	*n*	Reaction time (mean ± SD)	*n*	Reaction time (mean ± SD)	Time period	Estimate ± SE	*P* value	BF	*P* value	BF
N-back task, ms								11.39		22.09
Baseline	208	2.5 ± 2.8	208	3.3 ± 13.0						
0.5 h	213	2.3 ± 4.8	211	2.5 ± 4.6	0.5 h − baseline	0.7 ± 1.2	0.566		0.775	
2.5 h	211	2.1 ± 2.1	208	3.4 ± 21.6	2.5 h − baseline	−0.8 ± 1.2	0.528		0.727	
5 h	210	1.9 ± 2.2	209	1.7 ± 1.2	5 h − baseline	1.1 ± 1.2	0.371		0.043	
Reaction Time test, ms								12.01		17.28
Baseline	215	0.5 ± 0.4	213	0.5 ± 0.4						
0.5 h	215	0.4 ± 0.2	213	0.4 ± 0.2	0.5 h − baseline	−0.0 ± 0.0	0.693		0.994	
2.5 h	214	0.4 ± 0.3	210	0.4 ± 0.2	2.5 h − baseline	0.0 ± 0.0	0.778		0.782	
5 h	213	0.4 ± 0.2	211	0.4 ± 0.2	5 h − baseline	−0.0 ± 0.0	0.631		0.811	
Cognitive distraction, s								13.13		14.20
Baseline	213	0.6 ± 0.4	213	0.6 ± 0.5						
0.5 h	214	0.6 ± 0.4	213	0.6 ± 0.3	0.5 h − baseline	0.0 ± 0.1	0.483		0.527	
2.5 h	212	0.6 ± 0.3	209	0.5 ± 0.4	2.5 h − baseline	0.1 ± 0.1	0.262		0.215	
5 h	210	0.6 ± 0.4	205	0.5 ± 0.3	5 h − baseline	0.1 ± 0.1	0.207		0.248	
Emotional distraction, s							9.24			13.34
Baseline	215	0.4 ± 0.2	213	0.4 ± 0.2						
0.5 h	215	0.4 ± 0.2	213	0.4 ± 0.2	0.5 h − baseline	0.0 ± 0.0	0.656		0.999	
2.5 h	214	0.4 ± 0.2	210	0.4 ± 0.2	2.5 h − baseline	0.0 ± 0.0	0.670		0.668	
5 h	213	0.4 ± 0.2	211	0.4 ± 0.1	5 h − baseline	0.0 ± 0.0	0.608		0.644	
Sensory distraction, s								17.88		17.94
Baseline	214	0.4 ± 0.2	213	0.4 ± 0.2						
0.5 h	215	0.4 ± 0.17	213	0.4 ± 0.2	0.5 h − baseline	−0.0 ± 0.0	0.620		0.975	
2.5 h	214	0.4 ± 0.18	210	0.4 ± 0.1	2.5 h − baseline	0.0 ± 0.0	0.332		0.205	
5 h	213	0.4 ± 0.14	211	0.4 ± 0.1	5 h − baseline	0.0 ± 0.0	0.892		0.660	
Flanker task, ms								24.19		
Baseline	211	58.4 ± 43.1	211	60.0 ± 41.9						
0.5 h	210	51.1 ± 40.1	209	46.1 ± 37.3	0.5 h − baseline	7.8 ± 9.0	0.386			
2.5 h	211	42.7 ± 35.2	202	45.2 ± 32.2	2.5 h − baseline	−2.8 ± 8.5	0.745			
5 h	208	40.1 ± 39.4	207	43.4 ± 36.0	5 h − baseline	−4.6 ± 8.0	0.567			
RVIP test								26.08		
Baseline	208	0.9 ± 0.1	211	0.9 ± 0.1						
0.5 h	209	0.9 ± 0.1	211	0.9 ± 0.1	0.5 h − baseline	0.0 ± 0.0	0.779			
2.5 h	207	0.9 ± 0.1	209	0.9 ± 0.1	2.5 h − baseline	0.0 ± 0.0	0.559			
5 h	207	0.9 ± 0.1	205	0.9 ± 0.1	5 h − baseline	0.0 ± 0.0	0.888			

[1]Treatment effect is from linear mixed models, accounting for the correlation between visits, with pooled results after multiple imputation with 20 imputed datasets ($n = 223$); treatment effect is calculated as change from baseline with energy drink minus change from baseline with placebo. BF, Bayes factor; RVIP, Rapid Visual Information Processing.

[2]Analyses were also performed on log-transformed data that were skewed (Flanker and RVIP data were normally distributed, so logs were not needed).

of time on the N-back task after 5 h, and reported "alertness" in question 2 of the General Status Check instrument). It is important to appreciate that analyses of these types of cognitive tests aim to find even small effects (which may or may not have a noticeable "real world" impact on the consumer); therefore, finding no significant effect of drink type across all of the analyses strongly argues against the caffeine-free energy drink product having a meaningful effect.

Several prior studies have assessed the effect of the same energy drink (caffeinated or decaffeinated) (2, 17, 37, 38), but none was optimal for drawing conclusions about efficacy of the decaffeinated product on s-energy. One of these studies was a small trial that assessed the relative effects of the caffeinated and decaffeinated drinks on blood pressure and s-energy in 20 adult volunteers (2). The study did not include a placebo drink, and subjects rated their s-energy only via a nonvalidated subjective scale at baseline and 1, 3, and 5 h after drink consumption. The authors found that the s-energy did not differ significantly between the caffeinated and decaffeinated drinks, but the decaffeinated drink did not raise peripheral blood pressure as did the caffeinated drink. Authors of the same study later performed a pooled analysis ($n = 30$) of individual subjects at baseline, 1, and 3 h, and found that both caffeinated and decaffeinated energy drinks significantly boosted energy level 1 hour after consumption, but caffeinated energy drinks had a significantly greater boost and it was sustained at least 3 h after consumption (17). In the 2 other reported trials, both of which which included a placebo group, the authors concluded that the caffeinated energy shots improved important aspects of cognitive function for up to 6 h compared with placebo (37) and had the

greatest sustained caffeine effects across the test parameters (38); however, the studies did not include testing of the decaffeinated version of the energy shot.

In contrast, our results, obtained using a robust design with a placebo control, show no significant difference in the caffeine-free energy drink compared with the placebo in the s-energy or alertness as measured by the General Status Check instrument, which is the tool that is most similar to the scale used by Kurtz et al. (2) In addition, we used multiple objective tests of cognitive, behavioral, and s-energy performance and found no evidence of an increased effect of the decaffeinated energy drink compared with the placebo.

In a recent study reported as a letter to the editor (17), the authors performed a pooled analysis of individual subjects ($n = 30$) from 2 previous studies (2, 16) to assess s-energy after drinking the caffeinated and decaffeinated versions of the energy drink assessed in the present study. The study results indicated that the caffeinated version caused significantly greater increases in s-energy than the decaffeinated versions, and that subjects who consumed the decaffeinated version showed increased s-energy (using the nonvalidated subjective scale) only at 1 h after consumption (but not beyond then).

In contrast, our results show no significant effect of the caffeine-free energy drink on subject performance on any of the various tests compared with placebo at multiple timepoints spanning 5 h. We compared means, median, and slopes and conducted many subset analyses, but no appreciable differences were observed. Again, the 2 previously reported studies did not employ a placebo arm, had very small sample sizes, and used the same nonvalidated scale to subjectively rate s-energy.

Some authors have argued that the cognitive-enhancing properties of energy drinks can be attributed to the combination of active ingredients, rather than solely to caffeine (39). There is, for example, literature supporting the role of the B vitamins in brain function as coenzymes and precursors of cofactors in enzymatic processes involved in the methylation of proteins, phospholipids, and monoamine and catecholamine neurotransmitters (40). However, a recent controlled trial found no significant differences in task performance, fatigue, or mood between adults consuming multivitamin and mineral supplements compared with those consuming placebo (41).

Also, a controlled trial assessing the effects of energy drinks containing caffeine, taurine, and glucose alone and in combination on cognitive performance and mood in 24-h caffeine-abstained habitual caffeine consumers did not show reaction-time effects for simple or choice reaction-time tasks, which directly measure psychomotor performance (23). By ingredient, caffeine had the most consistent effects on cognitive performance. However, taurine opposed caffeine effects on mood, including reducing feelings of vigor. Though taurine had various effects on cognitive performance, the results were not sufficiently consistent to conclude an overall benefit (23). George et al. recently implemented a randomized controlled trial of caffeine's effects on mood and vigilance and found that some of the actual effects of caffeine differ according to the subject's expectation of receiving the active drug (42).

Lastly, a different line of research suggests that social influence can affect psychological and even physiological responses. For example, even plain water can have "energy" effects, especially when touted as such (15).

Because the current study did not test the effects of individual ingredients in the energy drink, we cannot draw firm conclusions about the effects of the individual ingredients on energy levels, though we found the ingredients in combination had no effect.

In light of the Dietary Supplement Health and Education Act, these findings may have labeling implications. The act states that "it is required that a manufacturer of a dietary supplement containing a statement of nutritional support on its label must have 'substantiation that such statement is truthful and not misleading'" (43). While judicial rulings to date have been mixed, a court in Washington State recently found that some of a major energy drink manufacturer's advertising was deceptive (44).

Our study has several strengths, including inclusion of a true placebo control arm; a crossover design, which eliminates any potential biases introduced by interindividual differences; use of validated, objective tools to assess changes in s-energy; utilization of both mood and cognitive tests; and inclusion of a large, demographically diverse sample of participants, which yielded sufficient power to detect even small differences in cognitive, behavioral, and s-energy-level performance. Limitations include the fact that we did not test the effects of the individual ingredients of the energy drink separately; moreover, we did not test other noncaffeinated energy drinks; and finally, these results do not extrapolate to caffeinated energy drinks.

In conclusion, there were no statistically significant or appreciable benefits detected in a range of mood, cognitive, behavioral, and s-energy tests after consuming a caffeine-free energy drink compared with a placebo drink in this large, diverse sample of adults. We found strong evidence that the energy drink was not efficacious in enhancing s-energy or any related cognitive behavioral variables measured.

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